DIAGNOSTIC METHODS: Original Research

Validity and reliability of the Modified Sphygmomanometer Test with fixed stabilization for clinical measurement of muscle strength

Brenno B.C. Silva [a], Ana C.T. Venturato [a], Larissa T. Aguiar [b], Luiz F.R.M. Filho [a], Christina D.C.M. Faria [b], Janaine C. Polese [a, b, *]

[a] NeuroEixo, Faculdade Ciências Médicas de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil
[b] NeuroGroup, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil

ABSTRACT

Objective: To investigate the concurrent validity of the Modified Sphygmomanometer Test (MST) with fixed stabilization, compared to the portable dynamometer, and to verify its test-retest and inter-raterreliability.
Methods: Methodological study. The muscle strength of the following groups was measured: flexors and extensors of the wrist, of the hip, and of the knee and plantar flexors. The Tycos® aneroid sphygmomanometer and the Microfet 2® dynamometer were used. Stabilization was performed using the Mullingan® belt. Descriptive statistics were performed for characterization of the sample. To determine the validity of the MST with fixed stabilization, comparing it with the portable dynamometer, we investigated the correlation between the measurements obtained with the two instruments using the Pearson correlation coefficient. Intraclass Correlation Coefficient (ICC) was used to investigate inter-examiner and test-retest reliability ($\alpha = 0.05$).
Results: 59 individuals were included (1176 evaluations). A statistically significant correlation of moderate to high magnitude ($0.58 \leq r \leq 0.81$) was observed for concurrent validity of the MST with fixed stabilization versus the portable dynamometer for all muscle groups. Regarding inter-rater reliability, it was observed statistically significant ICC considered excellent to good ($0.72 \leq r \leq 0.94$) for all muscle groups. Regarding test-retest reliability, first evaluator presented good to excellent ICC ($0.64 \leq r \leq 0.94$), while second evaluator presented good to excellent ICC ($0.74 \leq r \leq 0.96$) for all muscle groups.
Conclusion: The MST with fixed stabilization is valid and reliable for clinical measurement of muscle strength and can overcome previous limitations reported in the literature.

© 2019 Elsevier Ltd. All rights reserved.

1. Introduction

The evaluation of muscular strength is essential in several health conditions, and muscle strength is fundamental for performing different daily activities (Souza et al., 2013; Martins et al., 2015a,b).The manual muscle strength test has been the most widely used method to evaluate muscle strength in the clinical context (Bohannon, 1995). This can be explained due to the agility and ease of applying the test, besides not presenting equipment costs (Conable and Rosner, 2011). However, manual muscle strength testing may present a possible inter-rater variation. In addition, it does not provide objective values, which characterizes it as a subjective test (Bohannon, 1995). Because it is not a continuous scale, a differentiation between degrees of muscle strength becomes difficult, for example if an individual has grade 4 or grade 5 according manual muscle strength. In this way, adequately quantifying muscular strength is useful to verify the effectiveness of treatment over time, since the clinician could measure even small gains in muscle strength, which may be crucial to increases in functional performance. On the other hand, the gold standard for evaluating isometric muscle strength is the portable dynamometer (Thorborg et al., 2010; Stark et al., 2011; Figueiredo et al., 2016). This is an easy-to-use, sensitive device for detecting muscular action and for performing objective, valid, and reliable measurements in several populations (Stark et al., 2011; Bohannon and Andrews, 1987; Wadsworth et al., 1987). Nevertheless, its relatively high cost and difficulties in importing it to some countries limits its use

* Corresponding author. NeuroEixo, Faculdade Ciências Médicas de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil.
E-mail address: janainepolese@yahoo.com.br (J.C. Polese).

in clinical practice.

For these reasons, studies have been carried out evaluating muscle strength through the Modified Sphygmomanometer Test (MST), which combines the advantages of the manual muscle strength test and the portable dynamometer (Souza et al., 2013; Martins et al., 2015a,b; Aguiar et al., 2016). The MST is a useful test for clinical practice and research. In addition, this alternative method dispenses with the disadvantages of the manual muscle strength test and the portable dynamometer (Souza et al., 2013). Several studies (Helewa et al., 1981; Kaegi et al., 1998; Suresh et al., 2008; Lucareli et al., 2010; Souza et al., 2013; Arruda et al., 2014; Martins et al., 2015a,b; Aguiar et al., 2016; Toohey et al., 2018) have described its use with adequate validity (Souza et al., 2014) with previously stipulated positions (Souza et al., 2013), and stabilization performed by the examiner.

Stabilization of the instrument and body segment by the examiner can influence the achievement of reliable results. For example, if the evaluator has less muscle strength than the muscle group to be evaluated, the evaluation will not be done in an isometric manner, since the evaluator will not be able to hold the limb steady, thus generating eccentric or concentric contractions, invalidating the test. Souza et al. (2014) presents as a possible limitation the parameter of difficulty faced by the examiner in stabilizing the body segment when the muscle group performed using maximum isometric force. In addition, it is important to take into consideration examiner fatigue after performing multiple evaluations. Thus, it is hypothesized that when using the MST with stabilization in a static and fixed place, the execution of the test could be facilitated in the clinical environment, thus making it possible to maximize its use without changing the quality standard.

Considering the need for sensitive assessments of changes, using valid, reliable, cheap, and easy-to-use instruments for the evaluation of muscular strength, the present study aimed to investigate the concurrent validity of the MST with fixed stabilization in relation to the portable dynamometer, as well as to verify the test-retest and inter-raterreliability of the MST with fixed stabilization to measure muscle strength in healthy individuals.

2. Methods

A double-blind methodological study (Portney and Watkins, 2009) was developed at the Faculdade Ciências Médicas de Minas Gerais, and approved by the Research Ethics Committee of the Institution (number 1828.602). The tests were performed in a laboratory, at pre-scheduled times with the participants, between March to August 2017.

3. Participants

The sample consisted of healthy volunteers recruited from the community. Individuals were included according to the following inclusion criteria: age> 18 years; able to understand the test; no prior surgery; no type of injury within one year in the limbs to be tested; no health condition that would contraindicate the performance of the tests, such as pain, or unstable cardiovascular conditions.

To determine the number of individuals to be included in the present study, a sample calculation was performed from the previous data (Balogun et al., 1990; Portney and Watkins, 2009). To determine the sample size for the Pearson Correlation Coefficient, that is, for the validity study, considering a Power $= 0.8$, $r = 0.69$ and $\alpha = 0.05$, a sample of $n = 18$ was found. A correlation between 0.50 and 0.69 is considered moderate effect size according to Munro (2015). The correlation coefficient of $r = 0.69$ was selected for the sample size calculation because it is high enough to be

meaningful, but it is not an artificially high correlation. When using statistical tests to investigate the correlation between variables, that is, for correlation analyses, it is important to have sample variability in relation to the outcome of interest, which is, in this study, muscle strength (Portney and Watkins, 2009). Therefore, to obtain a wide variability of muscle strength values, individuals were recruited considering different age groups (between 18 and 28 years, between 29 and 39 years and over 40 years), and sex (female and male).The recruitment was then carried out with the intent of including 18 individuals in each age group, thus totaling 54 individuals. Furthermore, sampling variability was attempted for sex (female and male).

Before data collection, eligible participants were informed about the objectives of the study and provided consent, based on previous approval from the ethics review board. Then, the participants underwent an interview and physical examination to characterize the sample for the collection of sociodemographic data. Participants were instructed not to perform physical activities on the day of data collection, such as bodybuilding, swimming and other exercise modalities. In addition, participants had their blood pressure, heart rate and respiratory rate measured before and at the end of the assessment of muscle strength. Those with blood pressure equal to or greater than 180×100 mmHg and heart rate greater than 120 bpm (Nelson et al., 2007) were precluded from starting the evaluation until stabilization of this vital data.

4. Muscle strength measurements

The digital Microfet 2®dynamometer was used to investigate the validity of the MST with fixed stabilization in relation to the dynamometer. Adequate inter-examiner and test-retest reliability of the dynamometer has been found in previous studies (Martins et al., 2015a,b; Aguiar et al., 2016; Silva et al., 2017).

A Tycos® brand aneroid sphygmomanometer with a measurement range of $0-304$ mmHg was used to perform the MST, in order to investigate the test-retest and inter-rater reliability of MST with fixed stabilization. For the evaluation using the MST with fixed stabilization, the modified sphygmomanometer was inflated to 100 mmHg, keeping the valve closed, to remove possible folds from the inflatable portion. The pressure was then reduced to 20 mmHg and the valve was resealed to prevent leakage, providing a measurement range from 20 to 304 mmHg (Souza et al., 2014). The modified sphygmomanometer was positioned parallel to the segment in order to resist the movement of the muscle group tested, and the force exerted was obtained by reading the manometer. Finally, a Mullingan® belt was used for stabilization of the limb. It is made from an inelastic material, and used as a restraint of the MST, in the role usually performed by the examiner. The Mullingan® belt position is described in Table 1 and is shown in Fig. 1.

5. Procedures

The assessment of muscle strength of the upper and lower limbs was performed by two previously trained examiners (evaluator-1 and evaluator-2). The dominant upper limb was defined as the one the individual used to write and the lower limb, the one used to kick a ball. Seven muscle groups were evaluated: wrist flexors and extensors, hip flexors and extensors, knee flexors and extensors, and plantar flexors. The order of the tests was randomized prior to each evaluation by means of a simple draw, to guarantee that the order of execution would not influence the results. Another examiner, also trained, performed the reading and recording of the data, so that the examiner who performed the measurement of muscle strength did not have access to these values (Souza et al.,

Table 1
Description of the muscular strength evaluation positions for the Modified Sphygmomanometer Test (MST) with fixed stabilization and with the Portable Dynamometer.

Musclegroup	Individual's position and position of the segment/joint	Place of attachment (Mulligan Belt)	Location of MST and portable dynamometer
Wrist Flexors	Standing, shoulder and wrist in neutral position, elbow flexed to 90°, and fingers flexed	Arm leaning on trunk	Between palmar region of the hand and in contact with the wall
Wrist Extensors	Standing, shoulder and wrist in neutral position, elbow flexed to 90°, and fingers flexed	Arm leaning on trunk	Between dorsal region of the hand and in contact with the wall
Hip Flexors	Sitting, straight trunk and arms crossed, hip and knee flexed to90° and feet unsupported	Anterior and distal thigh with maca	Anterior and distal thigh, in contact with the belt
Hip Extensors	Supine, arms crossed, hip and knee in neutral position	Distal third of the thigh with the bed	Posterior and distal portion of the leg, in contact with belt
Knee Flexors	Sitting, straight trunk and arms crossed, hip and knee flexed to90° and feet unsupported	Distal third of the leg with the bed	Posterior and distal portion of the leg, in contact with bed
Knee Extensors	Sitting, straight trunk and arms crossed, hip and knee flexed to 90° and feet unsupported	Distal third of the thigh with the bed	Posterior and distal portion of the leg in contact with belt
Plantarflexors	Supine, arms crossed, hip, knee and ankle in neutral position	Distal third of contralateral thigh with bed	Between plantar surface off forefoot, and in contact with the wall

Fig. 1. Measurement of muscle strength with the Modified Sphygmomanometer Test. (A) Wrist flexors and Wrist extensors; (B) Knee Extensors; (C) Hip flexors; (D) Knee flexors; (E) Plantar extensors; (F) Hip extensor.

2014). During the test, at each muscle contraction the following verbal stimulus was given to encourage the participant to perform maximum effort for 5 s: "One, two, three and go! Strength, strength, strength … relax" (Souza et al., 2014).Demonstration and a familiarization trial, to guarantee understanding of the procedure, was performed. After a one minute rest, maximum isometric contraction was measured with one trial (Souza et al., 2014). During the tests, the examiners instructed participants not to perform the valsava maneuver (Polito et al., 2004).

Both examiners (evaluator-1 and evaluator-2) evaluated seven muscle groups on the first day to determine the validity of the MST,

totaling 826 measurements, and on a second day, =seven days later, for test-retest and inter-raterreliability totaling 350 measurements.

6. Statistical analyses

Descriptive statistics were adopted, using central tendency and dispersion measures for the quantitative and frequency for categorical variables to characterize the sample. Normality of data distribution was tested using the Shapiro-Wilk test, which was confirmed. To determine the validity of the MST with fixed stabilization, comparing it with the portable dynamometer, we

investigated the correlation between the measurements obtained with the two instruments using the Pearson correlation coefficient. For the correlations that presented significant results, its magnitude was classified as follows: 0—0.25 very low; 0.26—0.49 low; 0.50—0.69 moderate; 0.70—0.89 elevated; 0.90—1.00 very high (Munro, 2015). In relation to inter-rater and test-retest reliability, the Intraclass Correlation Coefficient ($ICC_{2,1}$) was used. To determine the test-retest and inter-raterreliability of the MST with fixed stabilization, the ICC with 95% confidence interval (CI) was used. In this study, the following values were used to determine the correlation between the variables: ICC: $\leq$0.4: poor; 0.4 < ICC $\leq$0.75: moderate to good; ICC:> 0.75: excellent (Munro, 2015). In all analyses the level of significance considered was $\alpha = 0.05$ and the statistical package used was SPSS for Windows® version 17.0 (SPSS Inc., Chicago, IL, USA).

7. Results

The sample consisted of 59 individuals, 51% female, aged between 18 and 64 (35 ± 14) years. The individuals had schooling ranging from 4 to 20 (13 ± 3) years. The individuals used a range of none to seven medications, and presented none to three associated comorbidities (systemic arterial hypertension, diabetes and hypercholesterolemia). During the tests, two individuals, both males, surpassed 304 mmHg in the evaluation of the strength of knee extensors. These two measurements were excluded, since comparisons of the measurements would not be possible, leaving the other muscle groups. In addition, the data from three individuals were not used for reliability investigation because of the lack of availability of these volunteers on the second day of evaluation. No volunteers complained of pain during the tests or any kind of alteration of vital data that excluded them from the research.

Regarding the concurrent validity, a statistically significant correlation of high magnitude was observed for the following muscle groups: wrist flexors (r = 0.78) and extensors (r = 0.81), hip extensors (r = 0.74), and plantarflexors (r = 0.77). There was also a statistically significant correlation of moderate magnitude for the following muscle groups: hip flexors (r = 0.67), knee flexors (r = 0.65) and extensors (r = 0.74). Validity data can be seen in Table 2.

Regarding inter-rater reliability, a statistically significant ICC was considered excellent for the following muscle groups: hip flexors (ICC = 0.85), knee flexors (ICC = 0.94) and extensors (ICC = 0.83), and plantarflexors (ICC = 0.78). Moderate to good ICC was observed for: wrist flexors (ICC = 0.72) and extensors (ICC = 0.73), and hip extensors (ICC = 0.75).

For the test-retest reliability, an ICC considered moderate to good was considered for the evaluator-1, for the following muscular groups: wrist flexors (ICC = 0.64) and extensors (ICC = 0.65); ICC considered excellent for the following muscle groups: hip flexors (r = 0.81) and extensors (ICC = 0.81), knee flexors (ICC = 0.94) and extensors (ICC = 0.85), and plantarflexors (ICC = 0.87). For the evaluator-2, ICC was considered moderate to good for wrist flexors (ICC = 0.73); it was also observed excellent ICC for wrist extensors (ICC = 0.88), hip flexors (ICC = 0.89) and extensors (ICC = 0.85), knee flexors (ICC = 0.96) and extensors (ICC = 0.94), and plantarflexors (ICC = 0.85). Data regarding reliability can be seen in Table 3.

8. Discussion

The present study demonstrated that the MST with fixed stabilization had adequate concurrent validity as well as adequate test-retest and inter-rater reliability. To the best of our knowledge, this is the first study to investigate these measurement properties of the MST with fixed stabilization. The findings of the present study established the MST with fixed stabilization as an adapted method with adequate measurement properties, using a fixed stabilization, thus excluding a preexisting limitation for examiners with low muscle strength.

In the present study, the values of concurrent validity of the MST with fixed stabilization obtained with healthy individuals ranged from 0.58 to 0.81. These results corroborate a study published by Souza et al. (2014), which investigated the concurrent validity of MST for the measurement of lower limb muscle strength in individuals with chronic stroke and found the values raging from 0.51 to 0.90 with traditional MST. Although the values were similar, the MST with fixed stabilization becomes a good strategy to be carried out by the professionals for its ease during the evaluation, without presenting restrictions as to the difficulty in stabilization. Another study (Martins et al., 2015a,b) also investigated the concurrent validity of the MST for evaluation of upper limb muscle strength of individuals with chronic stroke and found reliability values ranging from 0.62 to 0.93. Due to the motor effects arising from this health condition, it would be expected that the individuals presented some type of compensation to perform the maximum isometric contraction, considering the possible muscular weakness presented. Thus, it is hypothesized that the use of fixed stabilization allows the assessment of strength to be more specific for this population and other individuals which present important muscle weakness, since it can be a method where compensation is avoided.

Regarding the test-retest reliability, we observed in the present study ICC values that ranged from 0.64 to 0.96 and inter-rater

Table 2
Values of muscle strength measurements obtained with the Modified Sphygmomanometer Test (MST, mmHg) with fixed stabilization compared to the Portable Dynamometer (DYN, kg).

Muscular group	r	p	Equipment	Mean ± SD (minimum-maximum)
Wrist Flexors	0.78	<0.001	MST	70 ± 17 (40—70)
			DYN	15 ± 8 (2—27)
Wrist Extensors	0.81	<0.001	MST	59 ± 15 (34—96)
			DYN	13 ± 6 (5—27)
Hip Flexors	0.67	<0.001	MST	100 ± 47 (30—284)
			DYN	31 ± 13 (6—68)
Hip Extensors	0.74	<0.001	MST	97 ± 23 (32—142)
			DYN	54 ± 29 (6—135)
Knee Flexors	0.65	<0.001	MST	94 ± 30 (40—160)
			DYN	20 ± 12 (6—75)
Knee Extensors	0.58	<0.001	MST	225 ± 192 (48—999)
			DYN	54 ± 29 (6—135)
Plantarflexors	0.77	<0.001	MST	156 ± 46 (60—262)
			DYN	57 ± 25 (4—119)

r = Pearson correlation coefficient; SD = Standard deviation.

Table 3
Measurements of muscle strength measurements obtained with the modified Sphygmomanometer Test (MST, mmHg) with fixed stabilization for inter-rater and test-retest reliability.

Muscular group			Mean ± SD (min-max)	Test-Retest (ICC/CI95% (min-max))	Inter-rater (ICC/CI95% (min-max))
Wrist Flexors	Examiner 1	Test 1	58 ± 13 (40–60)	0.64 (0.06–0.89)	0.72 (0.22–0.92)
		Test 2	55 ± 12 (35–70)		
	Examiner 2	Test 1	58 ± 12 (40–70)	0.73 (0.23–0.92)	
		Test 2	58 ± 11 (40–70)		
Wrist Extensors	Examiner 1	Test 1	48 ± 10 (35–60)	0.65 (0.07–0.89)	0.73 (0.23–0.93)
		Test 2	46 ± 9 (35–60)		
	Examiner 2	Test 1	46 ± 10 (38–65)	0.88 (0.58–0.96)	
		Test 2	49 ± 9 (39–65)		
Hip Flexors	Examiner 1	Test 1	66 ± 26 (30–110)	0.81 (0.41–0.95)	0.85 (0.51–0.96)
		Test 2	68 ± 29 30–120)		
	Examiner 2	Test 1	55 ± 20 (30–80)	0.89 (0.62–0.97)	
		Test 2	65 ± 28 (29–110)		
Hip Extensors	Examiner 1	Test 1	83 ± 11 70–100)	0.81 (0.39–0.94)	0.75 (0.26–0.93)
		Test 2	81 ± 15 (60–100)		
	Examiner 2	Test 1	76 ± 18 (50–100)	0.85 (0.50–0.96)	
		Test 2	81 ± 15 (60–100)		
Knee Flexors	Examiner 1	Test 1	72 ± 26 (30–110)	0.94 (0.78–0.98)	0.94 (0.79–0.99)
		Test 2	71 ± 30 (30–120)		
	Examiner 2	Test 1	79 ± 32 (40–140)	0.96 (0.85–0.99)	
		Test 2	74 ± 30 (30–120)		
Knee Extensors	Examiner 1	Test 1	139 ± 56 (50–220)	0.85 (0.51–0.96)	0.83 (0.45–0.95)
		Test 2	146 ± 55 (45–220)		
	Examiner 2	Test 1	137 ± 48 (60–220)	0.94 (0.75–0.98)	
		Test 2	147 ± 55 (50–215)		
Plantarflexors	Examiner 1	Test 1	137 ± 35 (80–180)	0.87 (0.55–0.96)	0.78 (0.33–0.94)
		Test 2	131 ± 44 (60–210)		
	Examiner 2	Test 1	127 ± 41 (80–180)	0.85 (0.50–0.96)	
		Test 2	129 ± 36 (74–182)		

SD = Standard Deviation; ICC = Intraclass Correlation Coefficient; CI = confidence interva

correlation of 0.72–0.94. In a recent study, Silva et al. (2017) presentedICC ranging from 0.45 to 0.94 for test-retest and 0.37 to 0.98 for inter-raterreliability with traditional MST. This study included young adults and assessed the following muscle groups: hip flexors and extensors, knee flexors and extensors, and palmar grip, population profile involved in both (young) studies. In the present study, the test-retest correlation for knee extensors was 0.94, whereas Silva et al. (2017) found ICC of 0.65 for evaluator-2. This difference between the results of the studies can be explained due to the difficulty of stabilizing healthy individuals due to higher muscle strength, sample that was included on the previous study. In the study conducted by Toohey et al. (2015), the traditional MST was used to evaluated the muscle strength of hip adductors and abductorsin soccer players.ICC values ranged from 0.77 to 0.91 for inter-raterreliability and 0.82 to 0.92 on the test-retestreliability. Although the previous study evaluated only hip abductors and adductors, the findings were also compatible with those of the present study.

The MST with fixed stabilization showed adequate validity and reliability for healthy individuals. This adaptation facilitates the assessment of muscle strength, since it results in less effort of the examiner, eliminates influences from external forces, and also avoids compensating alternative movements to perform the test of certain muscle groups. In addition, stabilization ensures that examiners who have less muscle strength than the individual being evaluated can perform the test, since stabilization is independent of the examiner. This is the first study which proposed the elimination of a limitation previously observed in the test (Souza et al., 2014).

8.1. Study limitations

The present study has some limitations. The measurement of only seven muscle groups limits the extrapolation of the findings to other muscles. The muscle groups included in the present study were those that present greater muscular strength and difficulty of stabilization. This being the case, the other groups with a smaller force production capacity, can be more easily stabilized by a manual therapist. In addition, it is not known whether the test with the proposed stabilization is valid and reliable for other populations, beyond healthy young individuals. It is important to notice that the wide observed CIs should be took into consideration, in order to extrapolate the results to clinical practice.

Evaluation of muscle strength in the clinical environment aims to classify a specific muscle group according to its degree of strength. Despite the attempt to isolate muscle groups and avoid compensations, it was not possible to infer if the individual used body weight or synergistic muscles to perform the movement. Future studies using electromyography during the evaluation could be performed with the objective of evaluating the inadequate use of these muscle groups during the tests.

9. Conclusion

The results observed in the present study demonstrated that the MST with fixed stabilization showed adequate validity and reliability for clinical measurement of muscle strength of healthy young individuals. The MST with fixed stabilization may be of great help in the clinical setting because of its easy use and the absence of the therapist stabilization.

9.1. Clinical relevance

- MST with fixed stabilization had adequate concurrent validity, test-retest, and inter-rater reliability for healthy individuals.
- The use of fixed stabilization excludes a preexisting limitation for examiners with low muscle strength for muscle strength assessment with MST.
- The use of fixed stabilization facilitates the assessment of muscle strength, since it results in less effort from the examiner,

eliminates influences from external forces, and avoids compensating alternative movements during the test.

Conflicts of interest

None.

References

Aguiar, L.T., Martins, J.C., Lara, E.M., et al., 2016. Dynamometry for the measurement of grip, pinch, and trunk muscles strength in subjects with subacute stroke: reliability and different number of trials. Braz. J. Phys. Ther. 20, 395–404.

Arruda, M.F., Bazaglia, J.A., Saravalli, G., et al., 2014. Strength and function gains in the elderly from isometric training with and without visual response. RBME20 309–314.

Balogun, J., Akomolafe, C., Amusa, L., 1990. Reproducibility and criterion-related validity of the modified sphygmomanometer for isometric testing of grip strength. Physiother. Can. 42, 290–295.

Bohannon, R.W., 1995. Measurement, nature, and implications of skeletal muscle strength in patients with neurological disorders. Clin. Biomech. 10, 283–292.

Bohannon, R.W., Andrews, A.W., 1987. Interrater reliability of hand-held dynamometry. Phys. Ther. 67, 931–933.

Conable, K.M., Rosner, A.L., 2011. A narrative review of manual muscle testing and implications for muscle testing research. J. Chiropr. 10, 157–165.

Figueiredo, I.M., Sampaio, R.F., Mancini, M.C., et al., 2016. Teste de força de preensão utilizando o dinamômetro Jamar. Acta Fisiátr 4, 104–110 ([article in Portuguese]).

Helewa, A., Goldsmith, C.H., Smythe, H.A., 1981. The modified sphygmomanometer - an instrument to measure muscle strength: a validation study. J. Chronic Dis. 34, 353–361.

Kaegi, C., Thibault, M.C., Giroux, F., et al., 1998. The interrater reliability of force measurements using a modified sphygmomanometer in elderly. Phys. Ther. 78, 1095–1103.

Lucareli, P.R.G., Lima, M.O., Lima, F.P.S., et al., 2010. Comparison of methods of measurement of the finger flexor muscles' strength through dynamometry and modified manual sphygmomanometer. Einstein 8, 205–208.

Martins, J.C., Teixeira-Salmela, L.F., Araújo, L.S., et al., 2015a. Reliability and validity of the modified sphygmomanometertest for the assessment of strength of upper limb muscles after stroke. J. Rehabil. Med. 47, 169–186.

Martins, J.C., Teixeira-Salmela, L.F., Castro e Souza, L.A., et al., 2015b. Reliability and validity of the modified sphygmomanometer test for the assessment of strength of upper limb muscles after. J. Rehabil. Med. 47, 697–705.

Munro, B.H., 2015. Correlation. In: LIPPINCOTT WILLIAMS & WILKINS. Stat MHCR, vol. 10, pp. 239–258.

Nelson, M.E., Rejeski, W.J., Blair, S.N., et al., 2007. Physical Activity and Public Health in Older Adults: Recommendation from the American College of Sports Medicine and the American Heart Association Circ, vol. 39, pp. 1435–1445.

Polito, M.C., Simão, R., Nóbrega, A.C.L., et al., 2004. Pressão arterial, frequência cardíaca e duplo-produto em séries sucessivas do exercício de força com diferentes intervalos de recuperação. RPCD 4, 7–15 ([article in Portuguese]).

Portney, L.G., Watkins, M.P., 2009. Foundations of clinical research: applications to practice. Stamford CT 3.

Silva, B.B.C., Lacerda, C.S.A., Roza, E.A., et al., 2017. Confiabilidade interexaminadores do teste e re-teste do esfigmomanômetro modificado em indivíduos saudáveis. An. Cien. 12, 38–45 ([article in Portuguese]).

Souza, L.A.C., Martins, L.C., Moura, J.B., et al., 2014. Assessment of muscular strength with the modified sphygmomanometer test: what is the best method and source of outcome values? Braz. J. Phys. Ther. 18, 191–200.

Souza, L.A.C., Martins, J.C., Teixeira-Salmela, L.F., Godoy, M.R., et al., 2013. Avaliação da força muscular pelo Teste do Esfigmomanômetro Modificado: uma revisão da literatura. Fisioter Mov 26, 437–452 ([article in Portuguese]).

Stark, T., Walker, B., Phillips, J.K., et al., 2011. Hand-held dynamometry correlation with the gold standard. Isokinetic Dynamometry: Syst. Rev. 3, 472–479.

Suresh, M., Nicholls, P.G., Das, L., et al., 2008. Voluntary muscle testing and dynamometry in diagnosis of motor impairment in leprosy: a comparative study within the INFIR Cohort Study. Lepr. Rev. 79, 277–294.

Thorborg, K., Petersen, J., Magnusson, S.P., et al., 2010. Clinical assessment of hip strength using a hand-held dynamometer is reliable. J Med Sci Sports 20, 493–501.

Toohey, L.C., de Noronha, M., Taylor, C., et al., 2015. Is a sphygmomanometer a valid and reliable tool to measure the isometric strength of hip muscles? A systematic review. Physiother. Theory Pract. 31, 114–119.

Toohey, L.A., Noronha, M., Taylor, C., et al., 2018. The validity and reliability of the sphygmomanometer for hip strength assessment in Australian football players. Physiother. Theory Pract. 34, 131–136.

Wadsworth, C.T., Krishnan, R., Sear, M., et al., 1987. Intrarater reliability of manual muscle testing and handheld dynametric muscle testing. Phys. Ther. 67, 1342–1347.